Commercial Test of a
350 H. P. Stirling Boiler

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A COMMERCIAL TEST
OF
350 H. P. STIRLING BOILER

A THESIS

PRESENTED BY

WILLIAM S. FURRY
AND
JAMES C. MATCHETT

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

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HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

MECHANICAL ENGINEERING

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A COMMERCIAL TEST OF A THREE HUNDRED AND FIFTY HORSE POWER BOILER.

In presenting this thesis, we desire to show the efficiency and evaporation of a 350 H.P. Stirling Boiler, with a Chain Grate, at various loads. This test is of a strictly commercial character and is not intended to be a scientific research from which a complete heat balance could be deduced.

DESCRIPTION OF BOILER AND SETTING.

The Stirling Boiler upon which this test was made was one of five, located in the power plant of Armour Institute of Technology, at Chicago, Illinois. The boiler consists of three upper or steam drums, and one lower or mud drum, connected by 3 1/4 inch lap-welded mild steel tubes bent in such a manner as to enter the drums radially. The three upper drums are connected by steam tubes and the first two have a set of tubes joining them below the water line. The steam drums are connected by water tubes to the mud drum. The drums are each 3 feet 6 inches in diameter and 13 feet in length and are constructed of the best quality of flange steel. There are two hundred and fifty water tubes and twenty steam tubes which furnish a heating surface of approximately 3500 square feet.

19485

The feed water is admitted in the rear upper drum and steam is taken off from the middle drum on which two safety

valves are also placed. The blow-off pipe is located at the bottom of the mud drum. There is a manhole in one end of each drum for the purpose of inspection and cleaning.

The boiler is inclosed by a brick setting having the following dimensions:- Length 18 feet 3 inches, Width 13 feet, Height 18 feet 5 1/2 inches. The boiler is not supported by the brickwork but rests upon wrought iron beams carried by wrought iron columns having cast iron foundations. The weight of the lower drum is sustained by the tubes so that it is free to move and thus take care of any unequal expansion or contraction that may take place.

A chain grate manufactured by the Green Engineering Company is used in connection with the boiler. This grate is 9 feet wide and 9 feet 2 inches long, giving an area of 82-1/2 square feet. The coal is fed onto this grate from a hand filled hopper extending across the front of the boiler. The depth of the fire is regulated by an adjustable sheet iron gate A fire-brick arch projects over the grate to within 1 foot of the first row of tubes. This arch absorbs heat and, becoming incandescent, ignites the green fuel as it is fed into the furnace. Fire-brick baffles are placed on the tubes in such a manner that the gases are constrained to pass up the first set of water tubes, down the second, and across the third. The hot

gases are thus brought into intimate contact with all of the heating surface.

The draft is produced by a 175 foot brick stack connected to the boiler by a sheet steel breeching. A damper located in the breeching may be used to regulate the draft.

A boiler of this type has many advantages over other water-tube boilers. As all of the tubes enter directly into the steam drums, disengagement takes place at a low velocity and, therefore, so little entrained moisture is carried up that the use of a dry-pipe is unnecessary. Scale does not readily adhere to the tubes, which are nearly vertical and through which there is a rapid circulation of water, but gravitates to the mud drum and is removed through the blow-off. The tubes are arranged in parallel rows thus facilitating cleaning, and as each set is but four tubes deep it is never necessary to destroy more than one perfect tube in replacing a defective one.

DESCRIPTION OF AUXILIARIES.

The feed water supplied to the boiler is taken from the returns of the heating system and the make-up water is passed through a Webster Vacuum Heater of the induced type. This feed water, having an average temperature of approximately 210 F., is then forced into the boiler by a Smith and Vail Duplex Pump.

Coal is transferred directly from the cars to the boiler room floor level, from which it is shoveled into the hopper.

The ashes are withdrawn by hand.

The chain grate is operated by a 3 H.P. vertical steam engine, the speed of which is controlled by a fly-ball governor. By adjusting this governor, the rate of travel of the grate is easily regulated. This engine is belted to a jack-shaft, and an eccentric on this shaft is direct-connected to a rocker-arm which operates the grate through a ratchet and train of gears. The connection between the eccentric rod and the rocker-arm is adjustable, so that the grate speed may be changed.

DESCRIPTION AND LOCATION OF TESTING APPARATUS.

For the purpose of testing this boiler, it was necessary to install the following apparatus:

Throttling Calorimeter,
Pressure Gauge,
Draft Gauge,
Recording Thermometer,
Water Meter,
Thermometer Cup,
Ferry Pyrometer,
Platform Scale,
Coal Bin for Weighed Coal,
Revolution Counter,
Ados CO_2 Apparatus.

The throttling calorimeter used was a Barrus Universal Steam Calorimeter. This differs from the ordinary throttling calorimeter by having an extra thermometer well which projects into a chamber on the pressure side of the orifice. Thus, by means of two mercurial thermometers, the temperatures of the normal and superheated steam may be obtained simultaneously. Two holes were drilled and tapped in the vertical section of a T directly above the boiler nozzle. A standard collecting nipple for the calorimeter was inserted into the lower opening and a "goose-neck" for the pressure gauge was screwed into the upper. The pressure gauge used was a 150 pound calibrated Bourbon test gauge with a 3 1/2" dial graduated to read in pounds.

A water manometer of the ordinary U form with a scale graduated to read to 1/4 inch was used as a draft gauge. The force of the draft was obtained by connecting this to a 1/4 inch pipe inserted in the breeching directly over the damper.

To obtain the temperature of the flue gas, a hole was drilled in the breeching as close to the setting as possible, and into this, the sensitive bulb of a Bristol Recording Thermometer was inserted. This bulb is connected by a flexible capillary tube, 25 feet in length, to the standard 8 inch thermometer. This thermometer consists of a helical Bourbon tube, filled with an inert gas, connected to a pen which traces a curve on a chart operated by a clock movement. The chart is

graduated to read in Fahrenheit degrees, and makes a continuous record for twenty-four hours.

A Worthington Meter was used to measure the feed water. This meter is calibrated to indicate U. S. Standard Gallons. The feed piping is so arranged that the water can go through the meter or be by-passed directly to the boiler. This arrangement is shown clearly in the accompanying diagramatic sketch of the piping. Provision is made for obtaining the temperature of the feed water by the insertion of a brass thermometer cup in the feed line as shown.

A revolution counter was attached to one of the train of gears which operate the grate and by means of the gear ratio, the speed of the grate could be determined.

A platform scale of 2000 pounds capacity, a wheelbarrow, and two galvanized iron baskets were provided for weighing the coal used during the test.

The percentage of carbon dioxide in the flue gas was determined by means of an Ados Recording Co. Apparatus calibrated with an Orsat Apparatus.

The Ferry Pyrometer was used to obtain the temperature of the furnace.

METHOD OF TESTING BOILER.

This test was made to conform as nearly as possible

with the standard code of the American Society of Mechanical Engineers for Boiler Testing.

Previous to the test all apparatus was carefully calibrated. The thermometers were compared with a standard thermometer by heating them in an oil bath and the gauge was calibrated on a Crosby Gauge Tester. The meter was calibrated by comparing the weight of water, forced through it at a rate and temperature very close to those used during the test, with the weight corresponding to the meter reading. The platform scale was checked with standard weights. The accompanying data and curves show the necessary corrections.

Before commencing to record data on any run the boiler was operated at the desired load for as long a period as was possible. During this time any inconsistency in the reading of apparatus was noted and corrected. All conditions having become constant, the coal in the hopper was leveled and the height of water in the gauge-glass was marked. A reading of the water meter was taken at this time and only weighed coal was subsequently fired. Throughout the run the following observations were made at regular intervals:-

Time,

Water Meter Reading,

Weight of Coal,

Draft,

Depth of Fire,

Speed of Grate,

Percentage of Co_2,

Temperature of External Air,

" " Boiler Room,

" " Feed Water,

" " Flue Gas,

" " Steam in Calorimeter.

Before the final readings of any run were made, the coal in the hopper was again leveled and the feed water brought to the same level as at the beginning of the test.

At first, the coal was weighed in a wheelbarrow and dumped into a bin from which it was shoveled into the hopper, but as this necessitated shoveling the coal twice, it was thought advisable to weight it in bushel-baskets and empty these directly into the hopper. An average sample of the coal used was taken and from this the heating value was obtained in a Mahler Bomb Calorimeter. In addition an analysis was made for the percentage of moisture and ash, and no attempt was made to weigh the refuse passing through the grate.

The services of three men were required to collect the data. The following scheme shows the duties of each man during a run:-

Director of Test.

(a) Keep General Log.

(b) Observe:-

1. Time
2. Water Meter
3. Feed Water Temperature
4. Air Temperatures
5. Flue Gas Temperature
6. Carbon Dioxide

First Assistant.

(a) Weigh Coal

(b) Maintain Steam Pressure Constant

Second Assistant.

(a) Observe:-

1. Calorimeter
2. Draft
3. Depth of Fire
4. Speed of Grate.

The general or running log was kept by the director of the test who tabulated thereon the data of the other observers. In this manner any inconsistency would immediately become evident.

DISCUSSION OF RESULTS.

The results of this test may conveniently be divided into two parts, the first part to include the first three runs and the second, the last two. This division is made because the conditions of operation were changed after the third run. During the first three runs the boiler was operated under the usual conditions and the water rate was found to be very low. The cause of this low evaporation was that the air, instead of passing through the grate, was passing around the rear end. A damper which would force the air through the fire was therefore inserted. The effect of this upon the efficiency and evaporation is very marked, as during the first three runs the efficiency was about twenty percent, while in the last two it increased to about fifty-five percent with an accompanying increase in the water rate. There was also another indirect cause for this increase in efficicicency, namely, during the first three runs the boiler would only carry about one third of its rated load and at light loads the efficiency is low. During the last two runs the boiler was working at an over load and the efficiency was consequently higher. On account of this change in conditions the relations existing between load and efficiency cannot be satisfactorily shown graphically.

It will also be noted that there was an increase in the percentage of CO_2 during the last two runs which indicates that the damper was effective in producing a better combustion.

As the openings through the grate were very small it was found impossible, even with a 7/8 inch draft in the breeching, to maintain the load with more than a 4 1/4 inch fire.

While the average quality of the steam is practically constant, for all runs the readings of the calorimeter showed a considerable variation in quality. This was probably due to the surging of the water in the boiler. The feed water being very close to 212 F. the factor of evaporation was nearly unity.

During the later part of the last run the temperature of the furnace was taken with a Ferry Pyrometer. The average temperature was found to be 2490 F. while the calculated temperature was 1750 F. This difference was probably due to the fact that the Ados apparatus was not working properly.

In working up this thesis the following references were consulted:-

Calorimeters - Schaeffer & Budenberg.
Helios - Heine Safety Boiler Co.
Handbook - Kent.
Steam Tables - Peabody.
Steam Boilers - H. deB. Parsons.
Stirling Boiler Co. Catalogue.

May 25, 1907. Test No. 1.

Barometer 29.5" Hg.

Time.	Depth Fire	Grate Counter	Weight Coal	Draft In. H_2O.	Calorimeter.		% CO_2
					Temp. Steam	Temp. Superht.	
10:15	4.25"	8915		.875	320	212	6
10:30	"	8917	245	"	312	211	6
10:45	"	8923	602	"	312	211	6
11:00	"	8927	264	"	330	212	5.5
11:15	"	8931	497.5	"	320	212	6
11:30	"	8937	575	"	330	214	6.5
11:45	"	8941	301.5	"	336	214	7
12:00	"	8944	225	"	332	213	5.6
12:15	"	8948	201	"	326	212	5.5
12:30	"	8954	598	"	337	214	5.5
12:45	"	8958	642	"	346	215	7
1:00	"	8960	127	"	338	214	4.5
1:15	"	8965	503	"	329	214	5
Average	4.25"			.875"	329	213	6.1
Total		42	4583				

May 26, 1907.   Test No. 1.

Barometer 29.5" Hg.

Time.	Meter Reading	Gallons Water	Temperatures.				Steam Pressure
			Ex. Air	Boiler Room	Feed Water	Flue Gas.	
10:15	19757		79	72	203	532	78
10:30	19866	109		70	198	515	70
10:45	20042	176		78.5	190	515	71.5
11:00	20112	70	79	78.5	182	540	91
11:15	20259	147		81.5	202	520	78
11:30	20356	97		80	206	520	98
11:45	20506	150		81.5	205	500	100
12:00	20663	157		81.5	208	520	94
12:15	20821	158		82.5	205	500	96
12:30	20915	94		81.5	207	520	104
12:45	21042	127		71	206	540	119
1:00	21121	79	82	81	203	510	106
1:15	21281	160		[illegible]	207	500	81
Average			80.5	80.6	201.5	519.4	90.1
Total		1524					

May 20, 1907. Test No. 2.

Barometer 29.465" Hg.

Time.	Meter Reading	Gallons Water	Temperatures.				Steam Pressure
			Ex. Air.	Boiler Room	Feed Water	Flue Gas.	
9:35	25962			83	205	520	79
9:50	26078	116	62	84	203	525	79
10:05	26258	180	63	84.5	200	530	82
10:20	26375	117		84.5	200	515	70
10:35	26517	142		84.5	198	515	74
10:50	26645	128		82	199	520	77
11:05	26754	109	64	84.6	202	518	76.5
11:20	26859	105		85	202	520	82
11:35	27031	172		85.5	200	525	84
11:50	27100	69		86.3	193	530	85
12:05	27165	65	60	84	204	535	97
12:20	27293	128		86	198	540	80
12:35	27417	124	60	84.2	192	560	86
Average			61.8	84.4	199.7	527.1	80.9
Total		1455					

[illegible], 19[illegible]. Test No. 2.

Barometer [illegible],000" [illegible]

Time.	Depth Fire	Draft In. H_2O	Grate Counter	Weight Coal	Calorimeter.		% CO_2
					Temp. Steam	Temp. Superht.	
[illegible]	[illegible]"	.50			[illegible]	212	
[illegible]	"	"	[illegible]	72.5	[illegible]	[illegible]	
[illegible]	"	"	[illegible]	[illegible]	[illegible]	212.[illegible]	
[illegible]	"	"	[illegible]	126	[illegible]	[illegible]	
[illegible]	"	"	3000	[illegible]	[illegible]	21[illegible]	
[illegible]	"	"	[illegible]	[illegible]	[illegible]	212.[illegible]	
[illegible]	"	"	[illegible]	[illegible]	[illegible]	212.[illegible]	[illegible]
[illegible]	"	"	3010	[illegible]	[illegible]	211	[illegible]
[illegible]	"	"	301[illegible]	[illegible]	[illegible]	21[illegible]	
[illegible]	"	[illegible]	3017	[illegible]	[illegible]	212.[illegible]	
[illegible]	"	"	3021	[illegible]	[illegible]	21[illegible]	
[illegible]	"	"	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	"	"	[illegible]	[illegible]	[illegible]	21[illegible]	
[illegible]	[illegible]"	[illegible]"			[illegible]	[illegible]	[illegible]
Total			[illegible]	[illegible]			

May [illegible], 190[illegible]. Test No. [illegible]

Barometer 2[illegible].42" Hg.

Time.	Depth Fire	Grate Counter	Weight Coal	Draft In. H_2O.	Calorimeter. Temp. Steam	Calorimeter. Temp. Superht.	% CO_2
2:00	[illegible]	[illegible]	--	.75	[illegible]	21[illegible]	5
[illegible]	[illegible]	[illegible]	602	"	320	211.5	[illegible]
[illegible]	"	[illegible]	605.5	"	310	212	4.6
[illegible]	"	[illegible]	[illegible]	"	327	214	6.0
[illegible]	"	9052	620	"	310	213.5	[illegible]
[illegible]	"	9086	570.5	"	327.5	[illegible]	[illegible]
[illegible]:30	"	9094	474	"	328	211.5	[illegible]
[illegible]:45	"	9100	535	"	328	212	5.2
[illegible]	"	9106	592.5	"	322	212	[illegible]
[illegible]:15	"	[illegible]	[illegible]	"	321	[illegible]	[illegible]
[illegible]:30	"	[illegible]	244	"	320	21[illegible]	[illegible]
[illegible]	"	9127	709.5	"	322	211	[illegible]
[illegible]:30	"	9132	472.2	"	[illegible]	214	[illegible]
	[illegible]			.75	321.5	212.[illegible]	[illegible].2
Total		[illegible]	[illegible]				

Mar. 29, 190[illegible].   Test No. 2.

Barometer 30.[illegible] in. Hg.

Time.	Meter Reading	Gallons Water	Temperatures.				Steam Pressure
			Ex. Air.	Boiler Room	Feed Water	Flue Gas.	
2:00	28240		60	85.5	197.2	545	81
2:15	28450	210		85.5	198.5	555	79.0
2:30	28558	108		86	200	530	77
2:45	28754	196		84.5	200.0	565	[illegible]
3:00	28917	163	61	86.5	202.5	555	75
3:15	29029	112		87.0	200	560	70.8
3:30	29266	237		87	194.5	560	59
3:45	29378	112		88	199.5	570	60.0
4:00	29506	128	62	86.0	204	555	80
4:15	29639	133		86	203.5	565	75.5
4:30	29861	222		81	208	575	76
4:45	30106	245		84	197	547	62.5
5:00	30199	93	61	84.0	201.5	565	77.0
Average			60.5	[illegible]	200.[illegible]	[illegible]	[illegible]
Total		1959					

Mar. 11, 1907.   Test No. 4.

Barometer 29.3[illegible] Hg.

Time.	Meter Reading	Gallons Water	Temperatures.				Steam Pressure
			Ex. Air.	Boiler Room	Feed Water	Flue Gas.	
1:00	54005		53	78	205	550	120
1:15	55240	535		77.5	206	540	104
1:30	[illegible]	420		78	1[illegible]	580	95
1:45	[illegible]192	532		77	191	520	93
2:00	56525	443	54	77.5	198	525	108.5
2:15	56895	550		76.5	199	540	112.5
2:30	57240	345		76	204	520	84
2:45	57820	400		76.5	196	500	100
3:00	58165	325	55	79.5	194	545	115
3:15	58400	208		79	205	[illegible]	112
3:30	58585	225		76.0	207	550	110
3:45	59171	486		80	209	500	89
4:00	[illegible]	50[illegible]	54	[illegible]	180	560	97.5
Average			54	78	19[illegible].1	534.8	103.[illegible]
Total		4975					

[illegible] 21, 1917. [illegible] No. 1.

Barometer 29.[illegible]" Hg.

Time.	Depth Fire	Grate Counter	Weight Coal	Draft In. H_2O.	Calorimeter.		% CO_2
					Temp. Steam	Temp. Superht.	
1:00	1.25"	9150		.75	336	232	8.0
1:15	"	9152	[illegible]	"	335	230	[illegible]
1:30	"	9155	305	"	332	211.5	9.0
1:45	"	[illegible]	300.0	"	330	210	8.0
2:00	"	9160	264.5	"	330	210	10.0
2:15	"	9156	[illegible]	"	332	230	[illegible]
2:30	"	9166	307	"	324	23[illegible]	[illegible]
2:45	"	9175	302.5	"	334	210	[illegible]
3:00	"	9175	[illegible]	"	334	240	[illegible]
3:15	"	9180	285.0	"	335.0	261	[illegible]
3:30	"	9185	307	"	342	235	[illegible]
3:45	"	9192	287	"	332	230	7.5
4:00	"	9200	250	"	332	230	[illegible]
Average	[illegible]"			.75	[illegible]	[illegible]	[illegible]
Total		[illegible]	[illegible]				

June 3, 1907. Test No. 5.

Barometer [illegible] Hg.

Time.	Meter Reading	Gallons Water	Temperatures.				Steam Pressure
			Ex. Air.	Boiler Room	Feed Water	Flue Gas.	
8:30	98185		60	84	203.5	555	98.5
8:50	98556	371	63	82.5	205.5	560	89
9:10	99078	522		84.8	207	560	94.5
9:30	99729	651		85	207	565	95
9:50	100250	521		82.5	207.5	565	90
10:10	100812	562	65	85.4	208	570	89
10:30	101419	607		85.9	207	570	88.5
10:50	102027	608		87	207	565	89.5
11:10	102705	678	65	86.5	207.5	570	96.5
11:30	103142	437		87	209	555	98
11:50	103678	536		87.3	209	570	99.5
12:10	104208	530	63	87.5	209	565	102.5
12:30	104729	521		88.2	208	565	97.5
12:50	105210	481		88	208	565	101
1:10	105714	504	68	87.5	208.5	555	97
1:30	106215	501		88.5	208	565	99
1:50	106695	480		89	205	560	99
2:10	107200	505	67	87	210	555	[illegible]
2:30	107750	550		88	210.5	570	[illegible]
2:50	108410	660		87	203	570	91
3:10	108995	585	67	86.5	201	570	99
3:30	109554	559		85	202	560	90
3:50	110041	487		88.5	201	550	96
4:10	110502	461	66	89	200	560	94.5
4:35	[illegible]	[illegible]		87.5	201.5	560	93.5
Average			66.6	86.7	206.4	[illegible]	92.4
Total		12907					

[illegible] Test No. [illegible]

[illegible]

Time.	[illegible] Fire	[illegible]	Weight Coal	Draft In. H_2O.	Calorimeter.		% CO_2
					Temp. Steam	Temp. Superht.	
[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	
[illegible]	"		[illegible]	"	[illegible]	[illegible]	
[illegible]	"		[illegible]	"	[illegible]	[illegible]	
[illegible]	"	[illegible]	[illegible]	"	[illegible]	[illegible]	
[illegible]	"	[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]	"	[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	"	[illegible]	[illegible]	
[illegible]	"	[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]	"	[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]	"	[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]	"	[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]	"	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]		"	[illegible]	[illegible]	[illegible]
[illegible]			[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]	"	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	"	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Chain Grates No. [illegible]

Re[illegible]

Run ----------------	3	4	5
Date ---------------	[illegible]/28/07.	5/31/07.	6/3/07
Duration -----------	8	3	8
Thickness of fire -	-	4.25	[illegible]
Speed of grate ---	20	17.5	17.8
Steam pressure - g	88	103.0	[illegible]
Steam pressure - a	[illegible].5	117.6	109.05
Barometer ---------	14.4	14.4	14.30
Draft -------------	[illegible]	.75	.875
External air ------	60.5	69	69.8
Boiler room -------	[illegible]	75	80.2
Steam -------------	330.9	333.0	330.0
Flue gas ----------	555	420	[illegible]
Feed water --------	201	19[illegible]	208
Total amount of co	[illegible]	6336	14[illegible]07
Moisture in coal -	[illegible].7	5.7	5.9
Dry coal consumed -	[illegible]	5980	10[illegible]
Ash in coal -------	[illegible].5	8.5	[illegible]
Combustible consume	[illegible]301	[illegible]	1[illegible]42
Coal consumed per h	1075	1075	1050
Coal consumed per h	[illegible]	1774	1[illegible]0
Percentage of CO_2 -	[illegible]	[illegible].0	[illegible]
Quality of steam -	[illegible]	[illegible]	[illegible]
Percentage of moist	[illegible].7	[illegible]	[illegible]
Total weight of wat	[illegible]012	[illegible]	[illegible]
Water actually evap	[illegible]	[illegible]	[illegible]
Water evaporated pe	[illegible]	[illegible]	[illegible]
Factor of evaporati	[illegible]	[illegible]	[illegible]
Equivalent water ev	[illegible]	[illegible]	10048
Equivalent water ev	[illegible]	1[illegible]	135[illegible]
Water evaporated pe	[illegible]	[illegible]	[illegible]
Water evaporated pe	[illegible]	7.[illegible]	[illegible]
Cost of coal per 10	.0017	.00[illegible]	.00[illegible]
Equivalent evaporat	[illegible]	[illegible]	[illegible]
Equivalent evaporat	[illegible].62	[illegible]	[illegible]
Coal per sq.ft. of	[illegible]	21.[illegible]	[illegible]
Coal per sq.ft. of	[illegible]	[illegible]	21.[illegible]
Water evaporated pe	[illegible]	1[illegible].6	[illegible]
Equivalent evaporat	[illegible]	150.0	1[illegible]
Developed horse-p	[illegible]	[illegible]	[illegible]
Percentage of rate	[illegible]	10[illegible].0	104.1
Efficiency ---------	[illegible]	[illegible]	[illegible]
Heating value of co	13100	13100	131[illegible]

er

in-

f the

AVERAGE RESULTS.

[illegible] Grate surface [illegible] sq.ft.   Heating surface [illegible] sq.ft.
Ratio 1 to [illegible]
Rated Horse Power [illegible]

Test		1	2	3	4	5
Date		[illegible]	[illegible]	[illegible]	[illegible]	6/3/07
Duration	Hrs.	2	3	5	7	8
Thickness of fire	Ins.	[illegible]	4.2	5	[illegible]	4.25
Speed of grate	[illegible]	17.7	14.5	20	18.5	17.9
PRESSURES.						
Steam pressure - gauge	Lbs.sq.in.	[illegible]	[illegible]	[illegible]	[illegible]	94.2
Steam pressure - absolute	"	107.1	[illegible]	[illegible]	[illegible]	108.55
Barometer	"	14.5	14.5	[illegible]	[illegible]	14.36
Draft	In. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.876
TEMPERATURES.						
External air	Deg. F.	[illegible]	[illegible]	[illegible]	[illegible]	66.8
Boiler room	"	[illegible]	[illegible]	[illegible]	[illegible]	86.7
Steam	"	[illegible]	330.5	[illegible]	[illegible]	330.0
Flue gas	"	[illegible]	[illegible]	[illegible]	[illegible]	576
Feed water	"	[illegible]	[illegible]	[illegible]	[illegible]	208
FUEL.						
Total amount of coal consumed	Lbs.	[illegible]	[illegible]	[illegible]	[illegible]	14957
Moisture in coal	%	[illegible]	[illegible]	[illegible]	[illegible]	5.7
Dry coal consumed	Lbs.	[illegible]	[illegible]	[illegible]	[illegible]	14098
Ash in coal	%	[illegible]	[illegible]	[illegible]	[illegible]	8.5
Combustible consumed	Lbs.	[illegible]	[illegible]	1201	[illegible]	12342
Coal consumed per hour - dry	"	[illegible]	1722	[illegible]	[illegible]	1762
Coal consumed per hour - as fired	"	[illegible]	[illegible]	[illegible]	[illegible]	1870
[illegible]	%	11	11	[illegible]	[illegible]	6.8
CALORIMETER.						
Quality of steam	%	[illegible]	[illegible]	[illegible]	[illegible]	96.1
Percentage of moisture	%	[illegible]	[illegible]	[illegible]	[illegible]	3.9
WATER.						
Total weight of water pumped into boiler	Lbs.	[illegible]	[illegible]	[illegible]	[illegible]	98954
Water actually evaporated - corrected for quality	"	[illegible]	[illegible]	[illegible]	[illegible]	95413
Water evaporated per hour - actual	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Factor of evaporation		1.01	1.01	[illegible]	[illegible]	[illegible]
Equivalent water evaporated into dry steam	Lbs.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Equivalent water evaporated into dry steam per hour	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ECONOMIC EVAPORATION.						
Water evaporated per pound of coal - actual	Lbs.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Water evaporated per pound of dry coal - actual	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pounds of coal per 1000 pounds of water		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Equivalent evaporation per pound of dry coal	Lbs.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Equivalent evaporation per pound of combustible	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
RATE OF COMBUSTION.						
Coal per sq.ft. of grate surface per hour - as fired	Lbs.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Coal per sq.ft. of grate surface per hour - dry	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
RATE OF EVAPORATION.						
Water evaporated per sq.ft. of water heating surface per hour - actual	Lbs.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Equivalent evaporation per sq.ft. of heating surface per hour	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
COMMERCIAL HORSE POWER.						
Developed horse power		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Percentage of rated horse power developed	%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Efficiency	%	[illegible]	[illegible]	19.65	[illegible]	[illegible]
Heating value of coal per pound	B.T.U.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

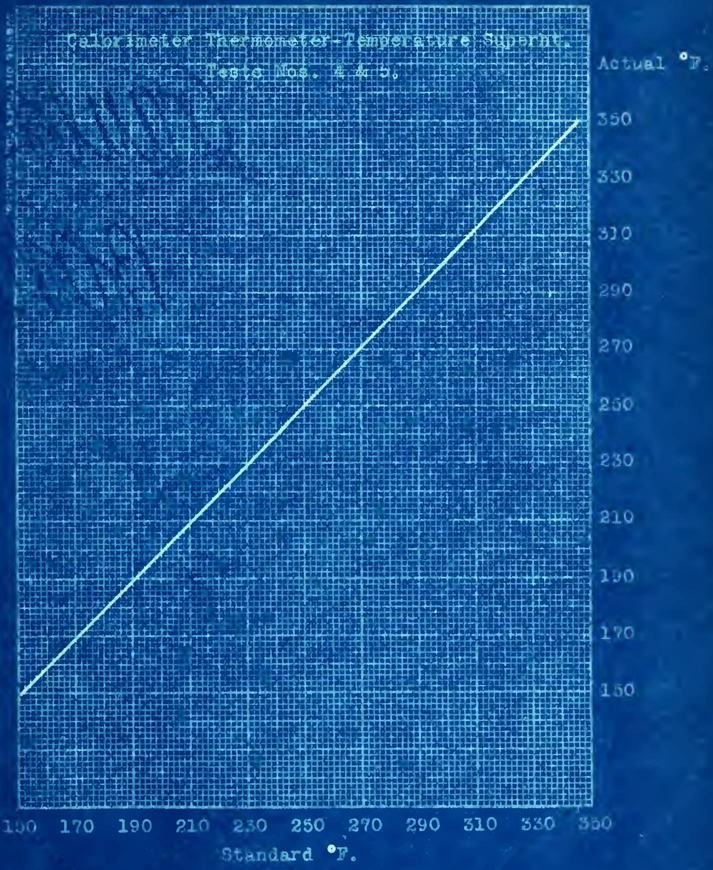
CALIBRATIONS.

A correction of -4.2% should be made on water meter total.

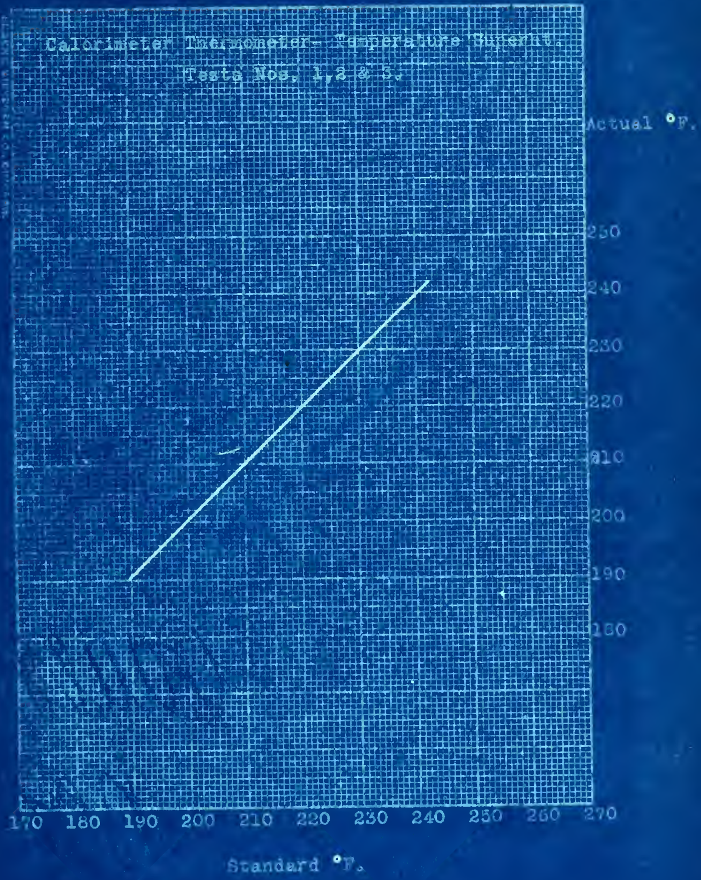
The grate moves 5 feet for every 5.5 revolutions indicated by the counter.

The following curves are the calibration curves of the thermometers and the gauge.

The platform scale was found to be correct.

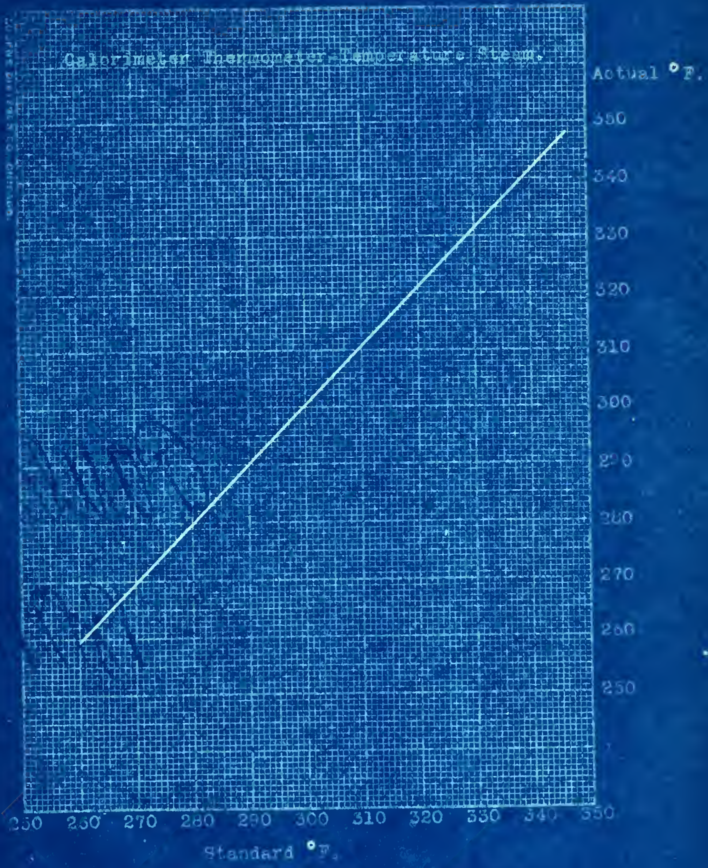


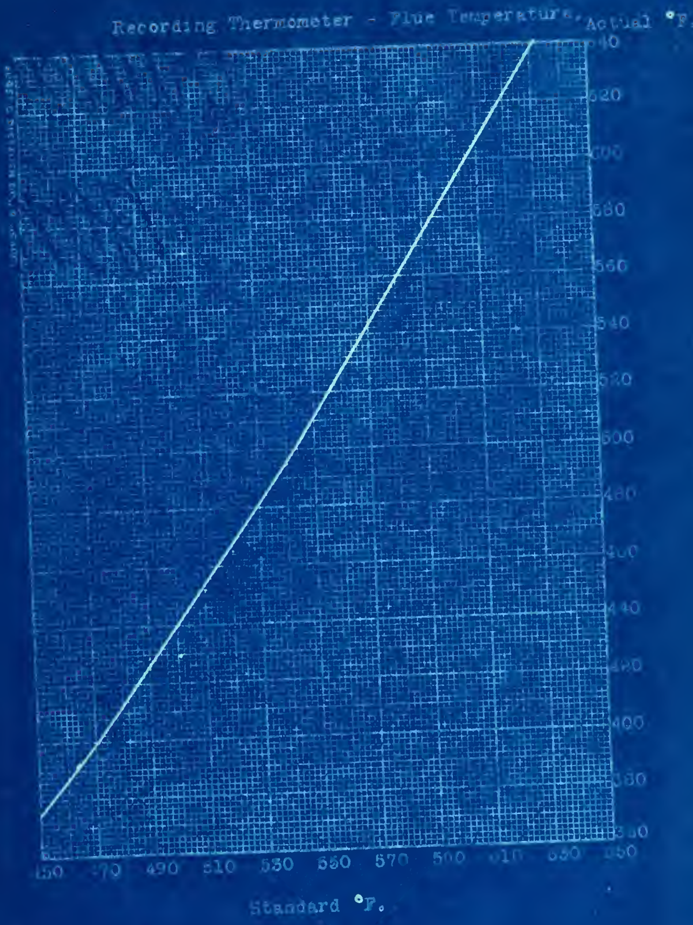
Calorimeter Thermometer-Temperature Superht.
Tests Nos. 4 & 5.

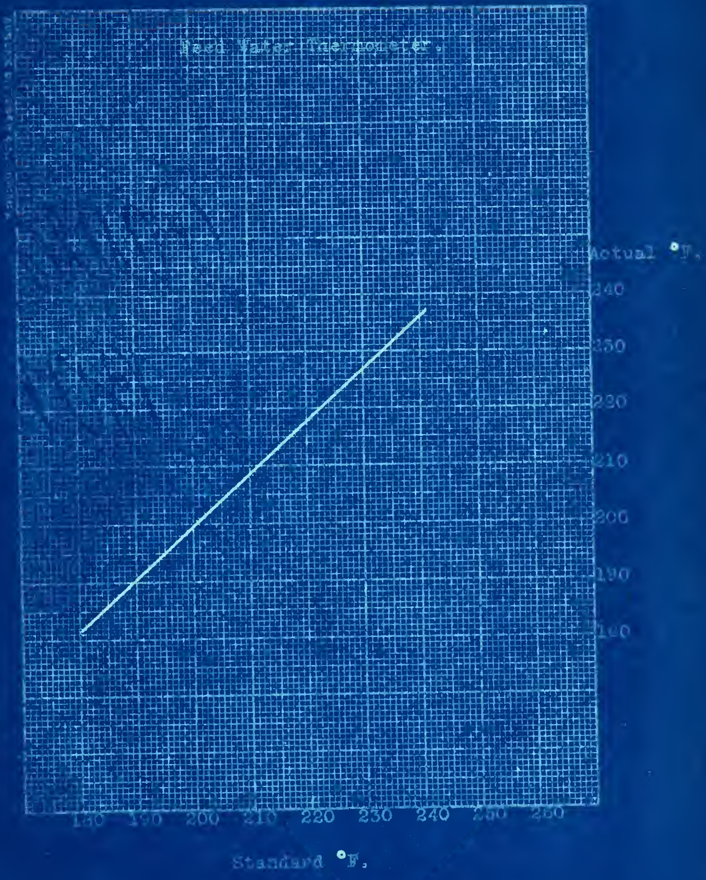


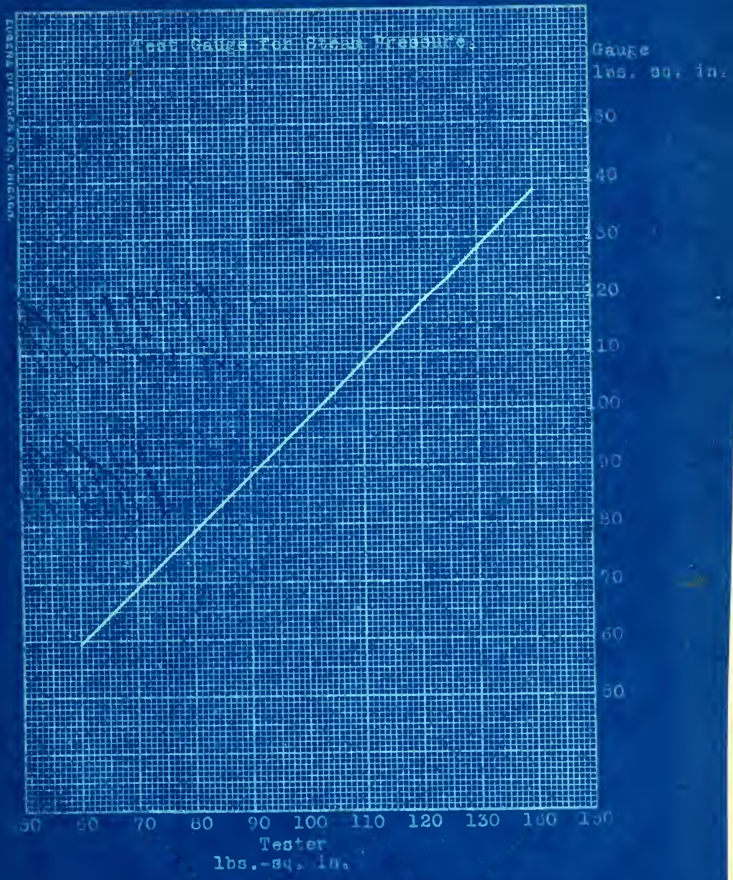
Calorimeter Thermometer- Temperature Superht.

Tests Nos, 1,2 & 3.

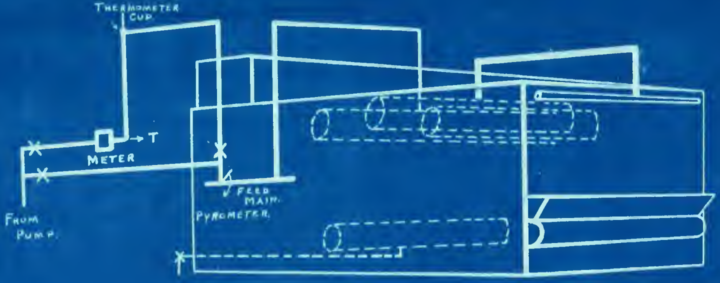

Calorimeter Thermometer Temperature Steam.


Recording Thermometer - Flue Temperature, Actual °F.


Feed Water Thermometer.
Actual °F.
240
230
220
210
200
190
180
180
190
200
210
220
230
240
250
260
Standard °F.


Test Gauge for Steam Pressure.
EUGENE DIETZGEN CO. CHICAGO.
Gauge
lbs. sq. in.
150
140
130
120
110
100
90
80
70
60
50
50
60
70
80
90
100
110
120
130
140
150
Tester
lbs.-sq. in.

The following table shows the results of similar tests upon boilers of various types.


THERMOMETER CUP
T
METER
FROM PUMP.
FEED MAIN.
PYROMETER.

BOILER AND PIPING.

FT $_2$O.	ST PRE	REFERENCE.
	10	EPORT COAL TEST PLANT L.P.E. PG. 587
	10	" " " " " 339
	10	" " " " " 363
	9	" " " " " 905
	12	U of I BULLETIN 8/15/06
		ENG. RECD. 5/7/04 PG 587
1	13	" " 2/19/98 " 258
1	13	" " 3/9/01 " 220
5	11	" " 7/25/03 " 102
2	9	" " 3/12/04 " 342
		POWER DEC. 1901 " 26

NO.	TYPE OF BOILER	MAKE OF BOILER	H.P.	KIND OF GRATE	KIND OF COAL	GRATE SURFACE SQ. FT.	DRAFT IN. H_2O.	STEAM PRESSURE	TEMPERATURE OF FEED WATER	LBS. COAL PER SQ.FT. GT. S.	ACTUAL EVAP PER LB. COAL	EQUIV. EVAP PER LB. COAL	EFFICIENCY OF BOILER AND GRATE	TONS COAL PER 1000 LBS. H_2O	REFERENCE.
1	Water Tube.	Heine Safety	210	Hand Fired.	Kansas No. 1.	40.55	.39	106.44	192.	18.13	7.09	8.22	65.65	.0706	Report Coal Test Plant L.P.E. P. 587
2	" "	" "	210	" "	Alabama No. 2.	40.55	.39	101.16	178.	21.54	6.92	8.13	65.68	.0720	" " " " " 339
3.	" "	" "	210	" "	Arkansas No 2	40.55	.35	104.26	188.5	15.70	8.29	9.63	65.96	.0603	" " " " " 363
4.	" "	" "	210	" "	W. Virginia No. II.	40.55	.52	96.7	188.	18.13	7.96	9.54	68.31	.0628	" " " " " 905
5.	" "	" "	350	Chain Grate	Oakwood-Vermillion County Screenings.	72.	.71	126.9	63.5	23.94	8.40	7.66	66.80	.0782	U of I Bulletin 8/15/06
6.	" "	" "	500	3/8" Mesh.	Coke Breeze.	80.5	.65			20.50	4.60	4.78		.1110	Eng. Recd. 5/7/04 P. 587
7	" "	Babcock and Wilcox	200	Hand Fired	Big Muddy	50.5	.29	138.2	104.2	20.80		9.369	67.0		" " 2/19/98 " 258
8.	" "	" "	250	Dutch Oven	Anthracite	56.	.42	134.1	212.5	9.80	10.40	10.90		.0481	" " 3/9/01 " 220
9	" "	" "	107	Hand Fired	Ill. Screenings.	25	.165	111.	151.4	20.1	10.48	11.50	73.84	.0477	" " 7/25/03 " 102
10	" "	" "	250	" "	" "	31.5	.42	94.4	172.1	18.65	4.60	4.86	41.5	.1050	" " 3/12/04 " 342
11.	" "	" "	412	Roney	Soldiers Mine Run	74.8	.47	154.4	64.3	22.40	8.63	10.387	69.9	.0586	Power Dec. 1901 " 26
12	" "	" "	412	"	New River	74.8	.34	158.5	71.3	21.00	9.68	11.576	74.9	.0517	" " " " "
13.	" "	" "	412	"	" "	74.8	.24	163.5	74.3	18.00	9.36	11.172	72.2	.0535	" " " " "
14.	" "	" "	107	Dutch Oven	George Creek M. R.	25	.16	148.6	166	14.80	8.76	9.518	84.54	.0572	Eng. Mag. Apr. 1904 " 96
15.	" "	" "	107	" "	Hackers Run Lump	25	.55	113.	53.2	29.07	6.90	8.30	58.74	.0725	" " " " " "
16.	" "	" "		Hand Fired	Daldowie Triping	45	.74	69	126	47.39	5.44	6.07	50.03	.0919	Engineering 2/15/95 " 227
17.	" "	" "		" "	" "	45	.78	65.3	124.3	45.97	5.40	6.04	52.71	.0926	" " " " "
18.	" "	" 149	420	Bennis Stoker		50		176.4	66.5	35.20	9.96	11.96	82.23	.0503	London Eng. 3/21/02 " 286
19.	" "	" "	107	Dutch Oven	George Creek M. R.	25	.19	150.3	156.1	20.00	9.00	9.88	66.99	.0556	A.S.M.E. Trans. June 1903 " 1153
20.	" "	" "	107	" "	" " " "	25	.23	150.4	158.6	23.60	8.65	9.47	64.24	.0578	" " " " " "
21.	" "	" "	107	" "	Pocahontas Lump.	25	.26	153.	165.	22.80	9.20	10.076	64.56	.0543	" " " " " "
22	" "	" "	107	" "	" "	25	.23	151.8	52.5	22.10	8.74	10.48	67.23	.0572	" " " " " "
23.	" "	" "	300	American Underfeed	Penn. Essen	65		257.	222.	36.90	8.79	9.24	75.30	.0569	Eng. News. Vol. 42. " 228
24.	" "	Cahall 116	200	Hand Fired		40	.14					11.84	78.70		Elec Rev 10/6/97 " 169
25	" "	Stirling	325	" "	White Ash M.R.	72.		113.3	185.3	25.55	6.92	7.39		.0723	Test-Armour Glue Works
26	" "	"	325	" "	" " " "	72.		107.	184.	33.10	6.08	6.49		.0822	" " " "
27	" "	"	325	" "	Zeigler Screenings.	72.		95.6	179.	28.40	6.75	7.16		.0741	" " " "
28	" "	"	325	" "	Carterville "	72.		113.	170	31.60	5.65	6.12		.0886	" " " "
29	" "	"	325	" "	" "	72		109.	178.	24.00	6.05	6.50		.0826	" " " "
30	" "	"	325	" "	" "	72.		109	176.	30.40	5.41	5.82		.0924	" " " "
31	" "	"	300.		Cumberland Geo. Creek	48.94	.45	136.1	116.6	21.74	9.08	10.38	76.75	.0550	Stirling Catalogue Pgs. 58-61
32	" "	"	200		Youghiogheny Lump	52.	.28	144.	168.	13.32	10.36	10.96	79.50	.0486	" " "
33	" "	"	600		Bituminous Slack.	90	.54	110.	71.	17.20	9.16	9.67	73.60	.0613	" " " "

STEAM RESSURE	TEMPERAT OF FEED WA	NCE
123.3	210	ATALOGUE Pgs. 58-61
196.8	96.2	D. 4/8/05 " 404
165.1	64.1	R DEC. 1901 " 26
162.5	64.5	" " " "
159.8	69.6	" " " "

NO.	TYPE OF BOILER	MAKE OF BOILER	H.P.	KIND OF GRATE	KIND OF COAL	GRATE SURFACE SQ. FT.	DRAFT IN. H_2O	STEAM PRESSURE	TEMPERATURE OF FEED WATER	LBS. COAL PER SQ FT. GT. S.	ACTUAL EVAP. PER LB. COAL	EQUIV. EVAP. PER LB. COAL	EFFICIENCY OF BOILER AND GRATE	TONS COAL PER 1000 LBS. H_2O	REFERENCE
34	WATER TUBE.	STIRLING.	250		CUMBERLAND GEO. CREEK	57.	.11	123.3	210	11.69	10.54	11.03	77.0	.0474	STIRLING CATALOGUE Pgs. 58-61
35	" "	"	620	BENNIS STOKER		72	2.0	196.8	96.2	71.9	8.84	10.44	84.9	.0565	ENG. RECD. 4/8/05 " 404
36	" "	"	517	AMERICAN UNDERFEED	REYNOLDSVILLE		.33	165.1	64.1		8.31	10.00	66.0	.0601	POWER DEC. 1901 " 26
37	" "	"	517	" "	SOLDIERS MINE RUN		.45	162.5	64.5		8.82	10.62	70.1	.0567	" " " " "
38	" "	"	517	" "	NEW RIVER.		.33	159.8	69.6		9.92	11.89	75.9	.0504	" " " " "
39	" "	"	517	" "	" "		.77	154.4	71.2		9.11	10.88	69.4	.0549	" " " " "
40	" "	"	517	" "	" "		.30	161.0	76.7		9.71	11.67	73.9	.0515	" " " " "
41	" "	"	60	HAND FIRED	MARION ODIN COUNTY LUMP	13.6	.25	97.0		19.91		6.57	54.5		U. OF I. BULLETIN 8/15/06
42	" "	"	520	" "	" " " DUFF.	50.9	.65	125.6	178.5	20.98		6.24	53.8		" " " " " "
43	" "	"	520	" "	OAKWOOD VERMILLION CO. LUMP	50.9	.79	127.3	182.8	25.42		6.63	51.0		" " " " " "
44	" "	"	520	" "	" " " SCREENINGS	50.9	.79	125.7	200.0	25.09		6.85	57.9		" " " " " "
45	" "	CLIMAX VERTICAL	500	" "	BOW AIR LUMP	109.3		125.5	61.0	22.72	8.12	10.06		.0612	MORRISON CLIMAX CATALOGUE
46	" "	" "		" "	NIXON NAVIGATION	64.0	.45	191.7	80.0	17.6	9.1	12.22	79.3	.0550	" " "
47	" "	" "	1000	WILKINSON STOKER	GEORGE CREEK	113.6	.21	96.	37.3	27.0	8.96	10.94	72.7	.0558	" " "
48	" "	NATIONAL	250	CHAIN GRATE	SANGAMON COUNTY PEA	55.8	.37	137.9	73.6	30.3		6.67	55.9		U. OF I. BULLETIN 8/15/06
49	FIRE TUBE	HORIZ. RETURN	60	HAND FIRED	HAZLETON CHESTNUT	19.9		88	200	7.7	8.28	8.66		.0604	BARRUS Pg. 68.
50	" "	" "	103	" "	CUMBERLAND BITUMINOUS	40.5		83	160	10.8	8.49	9.22		.0589	" " 72
51	" "	" "	395	" "	LACKAWANNA BROKEN.	120		99.6	198.6	11.11	8.50	8.96		.0588	" " 74
52	" "	" "	53	" "	CUMBERLAND GEO. CREEK BIT.	20		84.4	119.4	10.10	9.08	10.25		.0550	" " 79
53	" "	" "	100		ANGLE MINE RUN					6.94		7.37	51.35		ENG. NEWS 2/24/98 " 122
54	" "	" "	100		BONE					5.75		6.72	52.7		" " " " "
55	" "	SCOTCH MARINE	225	HAWLEY DOWN DRAFT	MARYLAND SMOKELESS	35	.78	151.2	162.4	30.69	8.73	11.10	79.0	.0574	" " 5/26/04 " 47
56	" "	" "	225	" " "	POCAHONTAS	35	.69	150.6	185.0	26.0	9.53	10.91	74.22	.0525	" " " " " "
57	" "	VERTICAL		HAND FIRED	"	28.3	.13	99.5	73.0	13.6	9.99	11.89	802	.0501	ENG. RECD. 4/3/98 " 590
58	" "	"	140	" "	DELEWARE - LACKWANNA	45.6		95	134	11.0	8.26	9.22		.0606	BARRUS Pg. 183
59	" "	"	75	" "	SCHUYLKILL ANTH.	15.9		76	125	15.4	7.98	8.95		.0626	" " 190
60	" "	"	140	" "	CUMBERLAND GEO. CREEK	45.6		87.7	44	7.3	7.83	9.46		.0639	" 193

Eng mig - Jard 107

24.5 g.s.

102.5 Gone

14.0 d ft

Geo Smith

13.2 0 8 stg g.

8.75 Li. coal

9.75 for a at

69 off

Indemnitä + E x time

.88%

[illegible]